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ANCHORING IN SNOW, ICE, AND PERMAFROST

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ANCHORING IN SNOW, ICE, AND PERMAFROST

by

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A literature search was conducted to identify techniques, procedures, and equipment that are used for anchoring in snow, ice, frozen ground, and permafrost in arctic regions. The results of that search together with findings and recommendations for future research and development is reported herein.

Anchors in snow, ice, frozen ground, and permafrost will creep in proportion to the magnitude of the load. Thus, the design of anchors to be placed in these media will be 47

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governed more by the displacements that can be tolerated than by uplift capacities.

Although many basic anchor configurations have been used for ground anchors, the applicability of such anchors for use in the media discussed above are somewhat limited. The more common anchor types that have been used in these materials include the following: round plate anchors (snow); pile anchors (ice); and dead man, piles, grouted rod anchors, hook anchors, arrowhead universal ground anchors, and various other small stake-like anchors (frozen ground and permafrost). Of all the anchors mentioned for frozen ground, the grouted rod anchor is believed to be the best. Analytical techniques to describe the behavior of anchors in these media have generally not been verified.

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INTRODUCTION

Objective

The objective of this study was to identify present techniques, procedures, and equipment being used for anchoring in snow, ice, frozen ground, and permafrost in arctic regions. Anchoring effectiveness depends on the properties of these materials; therefore, it is necessary to identify the properties of these materials in conjunction with the techniques, procedures, and equipment that are used for anchoring in such material. Based on findings, recommendations for future research and development of anchors and systems for use in such materials are offered.

Background

Anchors are used in snow, ice, frozen ground, and permafrost in arctic areas in various applications. These anchors may be portable and temporary or these may be permanent. Engineering structures such as towers and poles are tied down by anchors. Structures such as bridges and pipelines also utilize anchors. Anchors are used to tie down airplanes at airport aprons. Portable anchors have been designed to assist in extracting mobile equipment that has become bogged down in snow and other material.

Anchor capacity in any type of material depends on a number of factors. These factors relative to anchor capacity can be expressed as follows:

Capacity = f (shape, size, weight, depth, embedment medium properties, loading rate, load duration)

where

shape = the shape of an anchor is described by the relationship between the length, the width, and the height of the anchor

size = the physical dimensions describe the size of the anchor

weight = weight of the anchor

depth = this is the vertical distance from the embedment medium surface to the anchor

embedment medium properties = significant properties include unit weight, cohesion, and angle of internal friction, all of which affect bearing capacity in the medium, viscoelastic properties which affect creep in the medium, and adfreezing strength

loading rate = the speed at which the anchor is loaded

loading duration = the time duration [illegible] oad is applied to the anchor

From the above relationship it can be seen that the capacity for a given anchor is not a singular value but, conceivably, could have an infinite number of capacities up to the point where structural failure occurs in the anchor. As an example, if in a practical anchor application problem all of the factors in the equation above were kept constant except for shear strength of the embedment medium, it is readily seen that the anchor capacity will vary directly with shear strength of the medium. Thus, in order to establish the capacity of a given anchor, it is also necessary to determine the embedment medium properties, the rate at which loading will be applied, the duration of the load, and the depth at which the anchor will be placed.

A problem that could be encountered with anchoring in frozen ground is frost heaving [1].* The mechanism of frost heaving is very complex. This phenomena depends on a number of different factors including soil particle size, temperature of the soil, availability of water in the soil, heat flow, and pressure within the soil. Simply stated, however, frost heaving occurs by the growth of ice lenses within the soil mass. The growth of these ice lenses could force the anchor toward the surface of the ground, thus causing the depth of burial to be less thereby reducing the capacity of the anchor.

Frost heaving occurs only in materials where ice lenses can form and grow [1]. These materials are usually silts and clays. In materials where the voids are large enough such that the water in them behaves essentially like bulk water, frost heaving will not be experienced. Clean, coarse sands and gravels have voids large enough such that frost heaving will not occur in these materials.

Firm design data on forces exerted by a heaving soil on a structural surface have not been established [2]. The only reliable way of estimating the heave forces on any structural member is by actual field test or by observing structures at a site with identical conditions. In normal

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* Numbers in brackets refer to references listed at end of report.

practice, footings are not placed in the active zone where freezing and thawing can occur. Testing experiences in Alaska indicate that a 10-foot embedment in permafrost is safe in critical places of warm permafrost and air temperature extremes. The rule that embedment should equal twice the thickness of the normal active zone has been shown to be unreliable [3]. The importance of the structure should dictate the extent of the investigation to be performed to determine the depth of embedment of such structural components.

In the past when frost heaving became a problem to engineering structures, dead weight was used as a solution to these problems [2]. By increasing the dead load a simple and inexpensive means of anchoring against frost heave is accomplished providing that the bearing capacity of the supporting medium is not exceeded. Granular fill material has been used for increasing the dead load on footings. Concrete blocks have been cast on heaving columns in attempts to arrest further uplift of the columns due to frost heaving. Guy wire anchor problems due to frost heaving have been solved with dead weights.

As indicated above, concrete has been used as dead weight in solving frost heaving problems; however, the use of concrete presents problems in itself which will be discussed in a later section of this report.

PROPERTIES OF EMBEDMENT MATERIAL

Snow Properties

Information on the unconfined compressive strength of polar snow as related to density and temperatures has been compiled and analyzed by Kovacs [4]. In that analysis it was determined that unconfined compressive strength as related to snow density for snow temperature of $-10^{o}C$ can adequately be represented by the following equations.

For snow densities from 0.50 to 0.72 g/cm^3:

$$\sigma_c = 1719 (\gamma - 0.422) \tag{1}$$

For snow densities less than 0.5 g/cm^3:

$$\sigma_c = 962 (\gamma - 0.363) \tag{2}$$

For snow densities in the range of 0.36 to 0.72 g/cm^3:

$$\sigma_c = 988 - 6646\gamma + 13520\gamma^2 - 7235\gamma^3 \tag{3}$$

where σ_c = unconfined compressive strength, psi

γ = snow density, g/cm^3

The above relationships are shown in Figure 1. From this figure it can be seen that the first two equations describe the straight lines intersecting at a density of 0.5 g/cm^3. The analysis of the data indicate that at this density a structural change occurs in snow.

As qualified above, equations (1), (2), and (3) are applicable only to snow of -10°C and, therefore, unconfined compressive strengths determined by these equations must be corrected for temperatures other than -10°C. The following equation can be used to make the temperature corrections to the computed unconfined compressive strengths by the above equations.

$$\text{Log} \frac{\sigma_2}{\sigma_1} = 0.16 \text{ Log} \frac{\theta_2}{\theta_1} \qquad (4)$$

where σ_1 = unconfined compressive strength at temperature, θ_1 (°C)

σ_2 = unconfined compressive strength at temperature, θ_2 (°C)

Figure 2 illustrates the creep behavior of snow and ice as compared to an ideal Newtonian fluid and a Bingham soil. This figure is presented to show the shear stress-strain rate behavior of snow and ice as compared to these other materials. From this figure it can be seen that the viscosity (tangent u*) does not remain constant but is dependent on the shear stress and displacement rate. Since the viscosities of snow and ice do not remain constant for a given temperature but are dependent on the shear stress the behavior of these materials has been labeled as pseudo-plastic. From Figure 2 it can be seen that only under small stresses can the viscosity of snow be considered a constant. In the case of ice it behaves as an elastic body under the stresses of short duration but under long-term forces it behaves like a viscous fluid. Thus, ice can be further labeled as a viscoelastic material. Unlike snow and ice, the creep of soil begins only after a certain yield stress is exceeded. This rheological behavior places soils among the Bingham solids. This behavior not only depends on the type of soil and its water content but also on chemical and structural conditions.

Ice Properties

Approximate ranges of uniaxial compressive strength for ice and frozen soils at various temperatures are shown in Figure 3. From this figure it can be seen that the uniaxial compressive strength of ice

increases with a decrease in temperature. Since anchor capacity depends on the strength of ice, among other factors, as the temperature decreases the anchor capacity will therefore increase.

Like uniaxial compressive strength the creep behavior of ice is also highly dependent on temperature as is illustrated in Figure 4. Shown in this figure are two curves representing the shear stress strain rate behavior of ice at $0^{o}C$ and $-1.5^{o}C$. It can be seen from this figure that temperature will have a highly significant effect on the capacity and useful life of an anchor. Since ice creeps under a shear stress such as could be experienced from an anchor, a long-term useful life of an anchor will be governed by the amount of displacement that can be tolerated. For short-term applications, however, anchoring in ice appears to be feasible providing that shear stress is kept at a minimum.

Permafrost and Frozen Ground Properties

Uniaxial compressive strengths of silts, sands, and gravels are presented in Figure 3. The inclusion of that information on strength is not intended to be used as absolute values for design and analysis purposes but is included merely to demonstrate the increase in strength with respect to decrease in temperatures. In addition to temperature, the uniaxial compressive strength of a given frozen soil depends on the following factors:

Soil Type

Percent of Ice Content

Unit Weight of Frozen Soil

Viscoelastic Properties of Soil

Rate of Loading

Because of these many variables, it would be impractical to present strength properties for all soils to be encountered in anchoring operations. Depending on the application, sampling and testing of the frozen soil may be necessary and desirable.

The unconfined compressive strength behavior with respect to temperature of frozen clay, Ottawa sand, and sandy silt is shown in Figure 5. In this figure it can be seen that clays and Ottawa sand behave differently with respect to a decrease in temperature. Also shown in this figure is the effect of combining different sediment compositions, namely sand and silt, resulting in a different strength behavior. Thus, the soil composition of the frozen ground has a significant effect on the strength behavior.

BASIC ANCHOR CONFIGURATIONS

There are presently many basic anchor configurations [8]. These are described in Table 1 together with the installation technique, the retractability, and the limitations of each. Installation techniques of these anchors include the following:

a. Driving

b. Screwing

c. Augering, placing, and backfilling

d. Excavating, placing, and backfilling

e. Augering, placing, and grouting

f. Excavating, placing, and grouting

g. Drilling, placing, and backfilling

h. Drilling, placing, and grouting

The above techniques have been used for placing anchors in various soil and rock mediums which were not necessarily frozen; however, some of these techniques have been used in snow, ice, and permafrost as discussed later in this report.

A listing of patents on apparatus and methods for anchoring in ice and frozen ground is presented in Table 2. Further information on the effectiveness of these apparatus and methods was not located. It is also not known whether these apparatus and methods are currently being used for the specified purpose.

ANALYTICAL METHODS FOR ANCHOR CAPACITIES

Theoretical solutions to ground anchor capacity problems have been studied by Kovacs [9]. He stated that because soil and anchor parameters vary, no unique solution for all anchoring situations exists. The determination of the applicability of these theoretical techniques to snow, ice, and frozen ground anchoring problems is outside the scope of this study. However, since snow, ice, and frozen ground have unique properties a theoretical technique, for example, that is ideal for snow, may not be applicable to frozen ground. Similarly a particular theoretical technique may be applicable to one anchor configuration, but may not be applicable to another. Thus, for this report the theoretical techniques that are

available to analyze anchor holding capacities will simply be listed without qualifications. Such a list is presented as Table 3. The applicability of a given anchor analysis technique is often restricted by the ratio of anchor embedment depth to anchor base diameter, h/d. Those techniques that have h/d restrictions are so identified in that table.

ANCHORING IN SNOW

A study on the feasibility of buried anchors in polar snow was performed at Camp Century, Greenland, during the period 1962 to 1964 [10]. During the summer of 1962 a total of ten anchors were installed. Out of the installed anchors, eight were load tested during July 1962. The two remaining anchors were load tested in 1963 and 1964. The test configurations of the anchors were as shown in Figure 6. Each anchor tested consisted of a circular steel plate bolted to the ends of two 1-inch-diameter threaded steel tie rods. The tie rods which were used to apply the test load to the anchors varied in length depending on the embedment depth of the anchor. The dimensions of the anchors that were tested were as follows: 6-, 10-, and 14-inch-diameter plate 1/2 inch in thickness; and 12-inch-diameter plate of 1-inch thickness.

The test anchors were installed in holes of 1.21 feet in diameter and at embedment depths of 2, 4, 6, 8, and 10 feet below the surface of the trench floor. The holes were created by augering with a Mobile Drill. After the hole was created, the anchor was positioned in the hole at the predetermined embedment depth and the cavity was backfilled with the disaggregated snow removed during augering. The hole was backfilled and tamped with a 2x4-inch timber in 1-foot layers.

Temperature measurements were made of the snow adjacent to the anchors. During the 1962 tests dial thermometers were used to measure the snow temperature 0.5 foot below the trench floor. In the 1963 to 1964 tests a thermocouple assembly installed 15 feet from the test anchors was used to measure temperatures at 5-foot intervals to a depth of 40 feet below the trench floor. The temperatures observed around the anchors ranged from -19.6°C to -26.5°C.

Two types of controlled loading tests were performed on these anchors. The first type of test was designated as Quick Extraction Test in which load increments and applied duration varied from test to test. Upon completion of each load duration the next load increment was quickly applied and sustained for an equal time period. This method of loading was applied until failure occurred. An example of the results obtained in one of these tests is shown in Figure 7. As can be seen in this figure for a given anchor installation subjected to short-term loading, the displacement rate increases with increase in loading. Other findings from these tests include the following: (a) there appears to be a change in behavior of the snow at a ratio of embedment depth to anchor diameter (h/d) equal to 6; (b) for anchors 10 inches in diameter or larger and

buried at 6 feet or deeper, loads of 30,000 pounds can be sustained for months without shearing but with displacements; (c) for equally embedded and loaded anchors of different plate diameters, the smaller anchor plate showed more displacement per unit time but for the same unit bearing pressure the smaller plates experienced a smaller total displacement.

The second type of tests that were performed on these anchors were classified as Sustained Extraction Tests. Such tests were performed on two anchors during the 1963 to 1964 period. The first anchor was tested for 80 days at 10,000 pounds during the summer of 1963 and for 75 days at 20,000 pounds during the summer of 1964. The anchor displacements resulting from these loads were approximately 1.75 and 4.1 inches, respectively. The second anchor was subjected to loads of 5,200 pounds beginning in July 1963 for 350 days followed by 10,000 pounds for 50 days and concluded with 15,000 pounds for another 50 days, wherein the test was terminated. The time-displacement behavior of the anchor in this latter test is shown in Figure 8. The discontinuities in the curve at the points of load applications are due to the elastic elongation of the tie rods and elastic and plastic deformation in the snow above the anchor.

The behavior of the anchor in snow appears to be representable by the rheological model composed of a Maxwell and a Voigt body placed in series as shown in Figure 9. Immediately after the instantaneous plastic deformation, the decreasing creep rate behavior can be explained by the constant viscous flow in the Maxwell dashpot and the superimposed effect of the decreasing viscous flow in the Voigt dashpot as the spring in this body is loaded. The relatively linear creep behavior following the decreasing creep rate behavior above can be represented by the constant velocity, viscous flow in the Maxwell dashpot after the Voigt spring has assumed the full load.

In summary, anchors in snow can be effectively used for short durations at high loads but with large displacements. For small loads such anchors can be effective for longer durations and at smaller displacements. Anchors will creep in snow; therefore, the primary factor which will govern the design of such anchors will be the tolerable displacements.

ANCHORING IN ICE

Research has been performed by NCEL on short-term and long-term pullout resistance of different types of piles frozen into low salinity ice and backfilled with (1) fresh water, (2) fresh water-sand slurry, and (3) seawater [11]. The tests were performed on six different shaped piles as follows: modified H beam, H beam, steel pipe, steel box, tapered wood, and straight wood. The tests were performed in 1.6 ± 0.2 parts per thousand salinity ice, which was grown in a 53x71x40-inch deep insulated tank situated in a cold chamber. The grown ice thickness for the tests was about 22 inches.

The installation of the model piles required several operations. The first operation involved drilling 16-inch-deep holes with a dry auger either of 4-1/2- or 14-inch diameter to accommodate the different pile sizes. The pile was then positioned in the hole and the hole backfilled with prechilled (about 35°F) fresh water, seawater, or a sand slurry. After the piles were frozen-in, the ice was permitted to stabilize at the test temperature.

The characteristics of the model piles which were all 18 inches long were as follows:

Material	Size
Painted Steel Pipe	2.9-inch diameter
Straight, Dry Wood Cylinders	2.9-inch diameter
Steel Box Beams	2.4x3 inches 2.3x2.4 inches (3 inch)
WF Steel H-Beams	6x6 inches (6 inch) 10x9 inches (10 inch)

The pipe and box beams were sealed on the bottom.

In the short-term test it was shown that the tangential adfreezing strength varied with the type of material the pile was made of, the shape of the pile, the material that was used in the backfill and the temperature of the ice. The effect of the different types of material and the temperature of the ice on the tangential adfreezing strength is shown in Figure 10. The effect of the shape of the pile is also reflected in this figure.

The results of the long-term tests on WF steel H-beam piles are shown in Figure 11. From this figure it can be seen that temperature and possibly the size of the pile may influence its behavior. The effect of temperature can be clearly seen if the behavior of any one of the sizes of piles are compared for different temperatures. The effect of the size of the pile on its behavior is, however, not as apparent. If the behavior of the different sizes of piles at 10°F are compared, the data somewhat suggest that as the pile size increases the creep rate also increases.

The findings from these tests significant to this study include the following: (1) tangential adfreezing strength increases with decreasing temperature; (2) tangential adfreezing strength is greater than 100 psi at 10°F for all piles and all backfills; (3) tangential adfreezing strength depends on the backfill material, the size and shape of the pile, and the surface roughness of the pile. In installing the piles, dry augering should be used to develop the hole and backfilling should be performed in increments.

ANCHORING IN FROZEN GROUND AND PERMAFROST

As shown in Table 4, a number of different methods are used to anchor in frozen ground. These methods include utilizing the weight of the anchor itself and the overlying soil as in the case of the dead man anchor, utilizing the friction developed between the anchor and the soil such as in pile anchors, and utilizing the strength of the soil as in the case for the hook anchor.

Table 4 is not intended to be a complete listing of anchors for use in frozen ground. This table is intended to document the various types of anchors that have been reported as have been used in frozen ground or have been tested in such material.

The anchor types listed in Table 4 are installed by different techniques. In the case of the dead man anchor a hole is first excavated, the anchor positioned in the hole, and then the hole backfilled. In the case of pile anchors the following methods have been used in installation operations [12].

1. Prethaw soil at the pile location by a steam jet and drive the pile into the column of thawed soil.

2. Predrill for the pile to a diameter larger than the pile; set the pile in the predrilled hole and backfill with a soil-water slurry.

3. Predrill for a pile to a diameter smaller than the pile and drive the pile into the undersized hole.

4. Drive the pile directly into the ground with a pile driver without predrilling.

Other anchors such as the grouted rod anchor and the Long Thermopile are installed by first drilling a hole of the desired diameter and depth, then positioning the anchor at the desired location in the hole. In the case of the grouted rod anchor the steel reinforcing bar is positioned in the hole and the grout pumped in to the desired depth. In the case of the Long Thermopile when the anchor is in position, the space between the pile and the hole wall is backfilled with (from the bottom) a layer of uniform gravel, a layer of sandy gravel, and completed with a layer of sandy-clayey gravel. The remaining anchors in Table 4 which include the hook anchor; the arrowhead universal ground anchor; arctic adapter, drive pickets; and guy stake are all driven into the ground either directly or in pilot holes. The driving of these anchors into the ground has been either manually or by power equipment.

An effective method that can be used to produce pilot holes in frozen ground for tie-down stakes is by the use of the XM175 Blasting Demolition Kit developed by the Picatinny Arsenal [19]. This kit which

is low in cost and compact weighs only 28 pounds and has outside dimensions of 15 inches by 18 inches by 11 inches. Each kit is composed of four shaped explosive charges. Each charge is contained in a box such that it is positioned at the optimum standoff distance when placed on the ground. The kit is designed such that it can be unpacked, assembled, positioned, and fired in a matter of minutes without special training. The kit has been recommended for anchoring the Littlejohn Launcher in arctic terrains [20].

In the study for the Trans Alaska pipeline system it was concluded that several conditions could develop which would tend to raise the buried pipeline out of the ground [12]. The two conditions most likely to cause this uplift are due to thermal expansion of the pipe and due to buoyancy forces in areas of high ground water. Thermal expansion which causes axial loads in the pipe will tend to push the pipe out of the ground at overbends. A method that can be used to restrain the uplift of the pipe due to these conditions involves the use of anchored tension tendons tied to the soil or rock below the pipe. Anchors that can be used for this purpose include the following: conventional grouted rod anchors, explosive EAW-20 anchors, power-installed screw anchors, steel pipe pile and dead man anchor systems. The latter two anchor systems may not be as widely used as the others because of economy or technical limitation reasons.

Of the anchors discussed above, the grouted rod anchor is believed to be the best overall anchor system [12]. Tests on such anchors have been reported in Reference 13. The anchors tested were installed as follows: a #14S deformed steel reinforcing bar was grouted into a nominal 6-inch-diameter hole which was developed by a power auger or a Becker hammer drill. The length of the grout varied from about 8.5 to 10.5 feet. The anchors were placed at depths ranging from 12 feet to 24 feet. The grout used was composed of one part of high early strength cement, one part clean medium-to-coarse sand, and one-half part water (1:1:1/2).

The tests on the grouted rod anchors were performed at Thompson and Gillam in northern Manitoba. The mean temperature of the permafrost at these sites was approximately 31°F. At the Thompson site the frozen material consisted of stratified sediments (Varved clays*) to a depth of about 19 feet below which thinly stratified glacial drift consisting of a fine sandy gravel, a fine sand, or PreCambrian bedrock appears. In the upper stratified sediments occasional ice lenses to 1/4 inch in thickness appear. No ice was observed in the stratified glacial drift. At the Gillam site the top 3 feet was covered with moss and peat; below this depth the material was a silty clay to about the 14-foot depth, below which occasional small pebble and thin sandy silty layers occurred in the silty clay. Ice lenses occurred throughout the profile and varied from small crystals to lenses ranging from hairline to 4 inches thick. An occasional ice layer 8 to 9 inches thick with thin soil inclusions was also noted.

* Varved clays consist of alternate thin layers of clay and silt of glacial origin.

The findings from these tests showed that the three typical stages of creep displacement (primary, secondary, and tertiary) occurred for grouted rod anchors loaded in permafrost. This behavior is illustrated in Figure 12. From this figure it can be seen that after a certain amount of creep displacement the anchors begin to fail in a different mode. The failure mode is believed to be slip along the soil-anchor interface. This failure mode which was considered to coincide with the onset of tertiary creep began at different times under different loads but occurred at a total displacement of the same order of magnitude. This latter finding also suggests that the design of anchors in permafrost will be governed by displacement criteria rather than the pullout capacity of the anchor.

Figure 13 summarizes the steady state creep behavior for the anchors tested at the Gillam and at the Thompson sites. Note that for a given applied stress the steady state creep rate was about an order of magnitude different between the Gillam and the Thompson tests.

Effectiveness and Problems

Exploratory tests were performed on 2-, 4-, 6-, and 8-inch arrowhead universal ground anchors in frozen ground [16]. The tests were performed at a site in Hanover, New Hampshire, which contained a deposit of silt with varying amounts of clay and sand. The tests showed that the holding capacity of the anchors was governed by the breaking strength of the cable, the cable clamps, or the connection point on the anchor itself rather than the strength of the holding medium. This was the finding for all anchors irrespective of embedment depth in the material at the site.

Exploratory tests on hook anchors were performed by the Cold Regions Research and Engineering Laboratory [14]. Anchors of various shank lengths and diameters were tested in frozen and unfrozen ground. The anchors were installed manually with a 2-pound ball hammer according to a prescribed procedure as outlined by the manufacturer of the anchors. The driving time for the anchors was always less than one minute. The results of the exploratory tests are shown in Figure 14. As expected, it can be seen in this figure that the holding capacity of hook anchors was higher in frozen than in unfrozen ground and varied with anchor diameter and shank length. It was also found that anchor capacity was more sensitive to anchor diameter rather than shank length. For capacity and ease of installation, the hook anchor appears to be very effective for anchoring in frozen ground.

As noted earlier, grouted rod anchors are believed to be the best anchors for frozen ground. Tests have shown that effective anchoring can be achieved by the use of such anchors. However, the use of such anchors is not problem free. The primary problems that may be encountered in the use of such anchors include difficulty in developing the hole for the anchor and the improper curing of the grout material. If the appropriate constituents of the grouting material are not used and the grout

is permitted to freeze before curing the full anchor capacity may not be realized because of structural failure in the anchor. Such failures could occur at the bonding interface between the tie rod and the grout material or within the grout material itself if the grout was permitted to freeze while in the freshly placed state. In this latter case when the grout material becomes unfrozen due to seasonally warm temperatures the grout returns to its original uncured state, thus permitting the tie rod to be easily pulled out of the grout by the anchor load. Despite these problems which can be prevented, however, grouted rod anchors are an effective and relatively economical method for anchoring in frozen ground.

Of all the publications pertaining to anchoring in frozen ground none has delved into the problem of group behavior of anchors in such materials. Two significant reasons why it is desirable to have the knowledge of group behavior of anchors in frozen ground are: (1) it is generally easier to place a number of smaller anchors to hold a particular load rather than to place a large anchor that would hold the total load, and (2) the ultimate load of a group of small anchors may most likely not be equal to the number of anchors times the ultimate load on a single isolated anchor positioned at the same depth. A study to determine the effects of interference on the behavior of groups of anchor plates in sand has been reported in Reference 21. This study which was made on unfrozen sand showed that the ultimate resistance of a group of anchor plates in sand decreases as the distance between individual plates is decreased. In addition, considerable changes in the displacement characteristics occurred for the group of plates when compared to a singular plate. It is anticipated that the behavior of anchors in a group in frozen soil will also exhibit behavior that is different than for a singular anchor. It would therefore be desirable to investigate the behavior of anchors in a group in frozen soil. Since the behavior of group anchors will similarly be different in ice and snow such investigations should also be performed in these materials.

SUMMARY

Snow, ice, permafrost, and frozen ground all behave as a viscoelastic material under a loading such as from an anchor. Because of this behavior, the design of an anchor to be placed in this type of material will be governed more by the tolerable displacement relative to load duration rather than the uplift capacity of the anchor in the holding media. Displacement of the anchor through frost heave of the permafrost and soil is also a problem to adequate anchoring. Many analytical techniques have been developed to determine the theoretical uplift capacity of various anchors in unfrozen ground and rock, however, the applicability of these techniques to anchors in snow, ice, permafrost, and frozen ground have generally not been verified.

The types of anchors that have been used in frozen ground include deadman, piles, grouted (cement/sand) rod anchors, hook anchors, universal ground anchors, and various other small stake-like anchors. It is generally considered that the grouted rod anchor is the best in terms of effectiveness and economy for use in frozen ground. A significant problem associated with the grouted rod anchor is proper curing of the grout. If the grout is permitted to freeze during curing, a bond failure between the rod and the grout is likely to occur.

Round plate anchors have been tested for holding power in snow and are considered effective depending on magnitude and duration of the load.

Pile anchors of different shapes, sizes, and materials have been tested for holding power in ice. These tests showed that the tangential adfreeze strength depends on the backfill material, the size and shape of the pile and its surface roughness.

RECOMMENDATIONS

From this state-of-the-art review on anchors for snow, ice, permafrost and frozen ground, the following studies and investigations are recommended:

1. Further investigation should be made on round plate anchors for snow, ice, permafrost and frozen ground to determine:

   a. Critical depths for embedment

   b. Critical spacing for anchor groups

   c. Critical relationship between anchor diameter and plate thickness for the different embedment materials.

2. Perform similar investigations as in item 1, for arrowhead universal ground anchors for snow.

3. Develop lightweight expedient deployment anchors and array patterns primarily for ice, permafrost and frozen ground anchorage.

4. Develop lightweight equipment for installation and extraction of the lightweight anchor.

5. Conduct investigations to advance present theoretical knowledge of the viscoelastic and thermal properties of ice, permafrost and frozen ground.

6. Conduct investigations for methods to minimize frost heave problems with anchor systems.

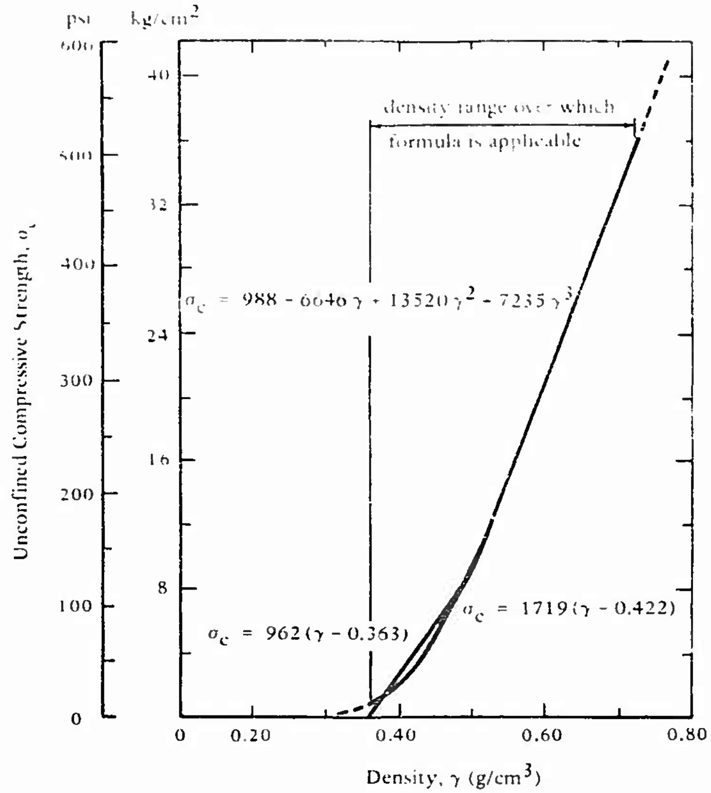


Figure 1. Linear unconfined compressive strength versus density relationships for data above and below the transition density of 0.50 g/cm^3 in relation to the polynomial relationship for the entire data range. Snow temperature -10°C. (From Reference 4.)

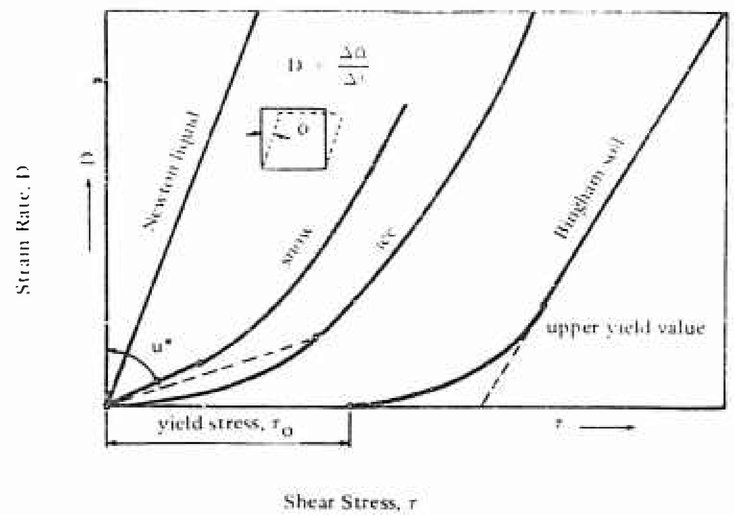


Figure 2. Flow curves for snow, ice and soil. (From Reference 5.)

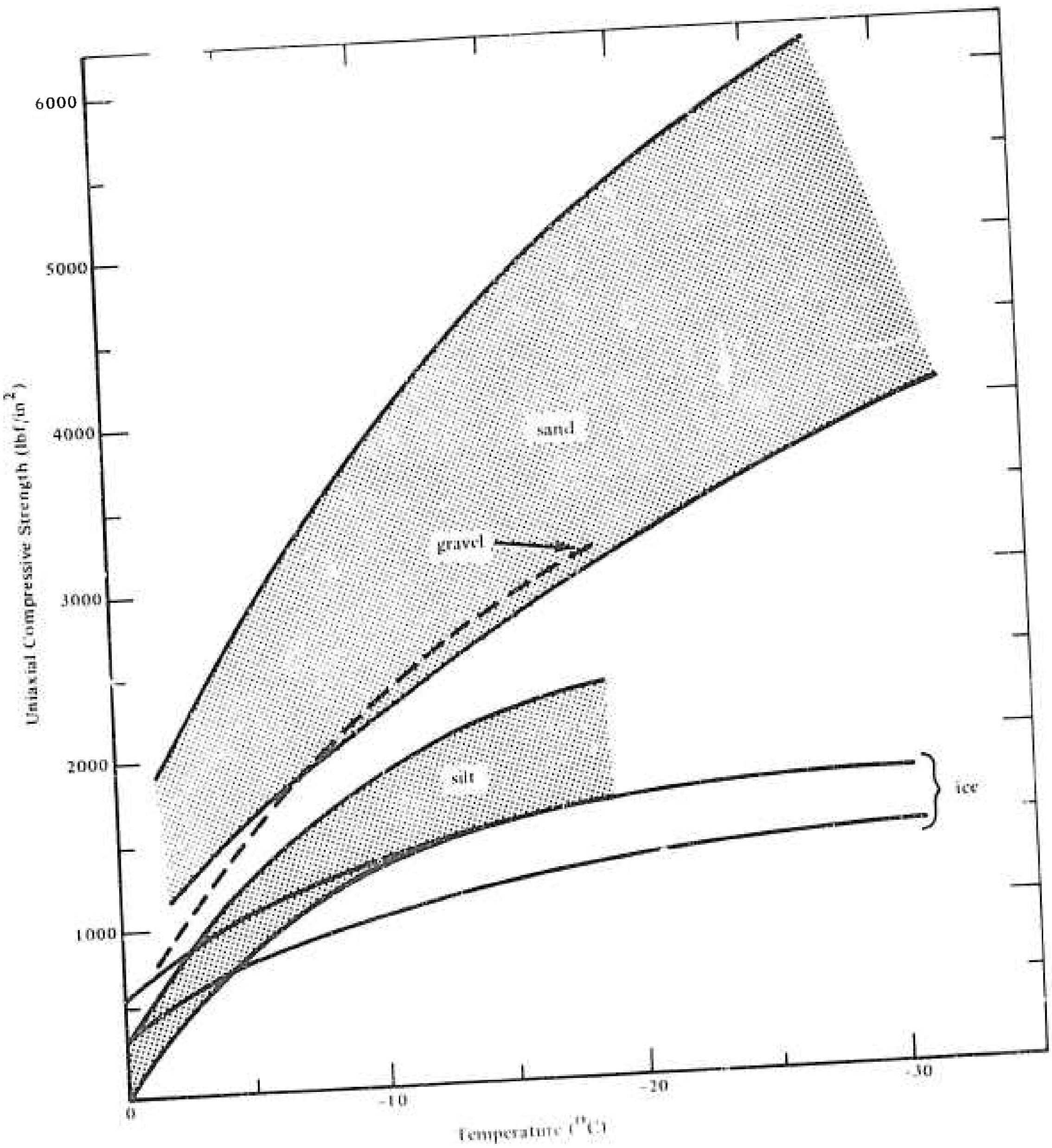


Figure 3. Approximate ranges of uniaxial compressive strength for ice and frozen soils. (From Reference 6.)

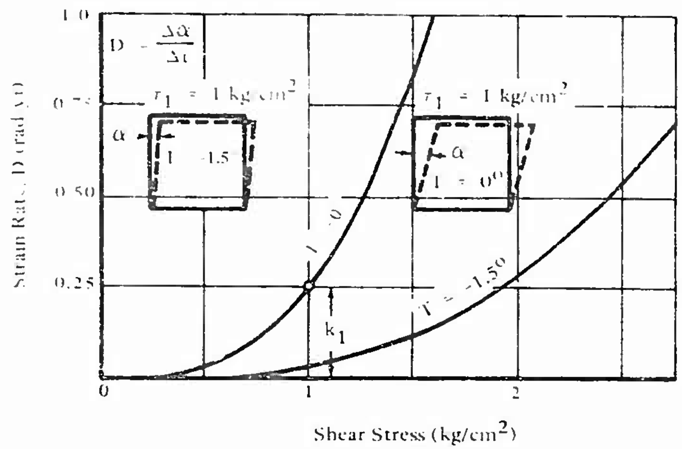


Figure 4. Flow curves for ice at two different temperatures. (From Reference 5.)

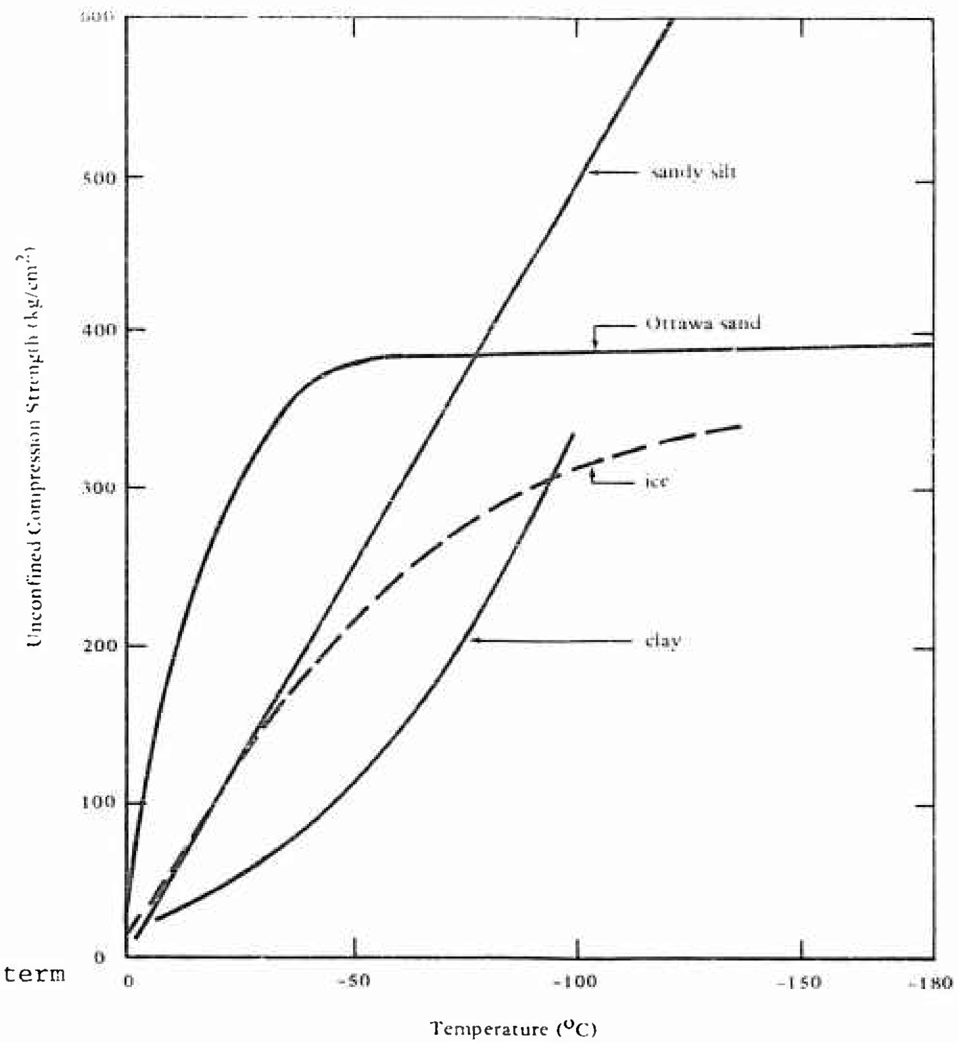


Figure 5. Effect of temperature on the short-term unconfined compression strength of various frozen materials. (From Reference 7.)

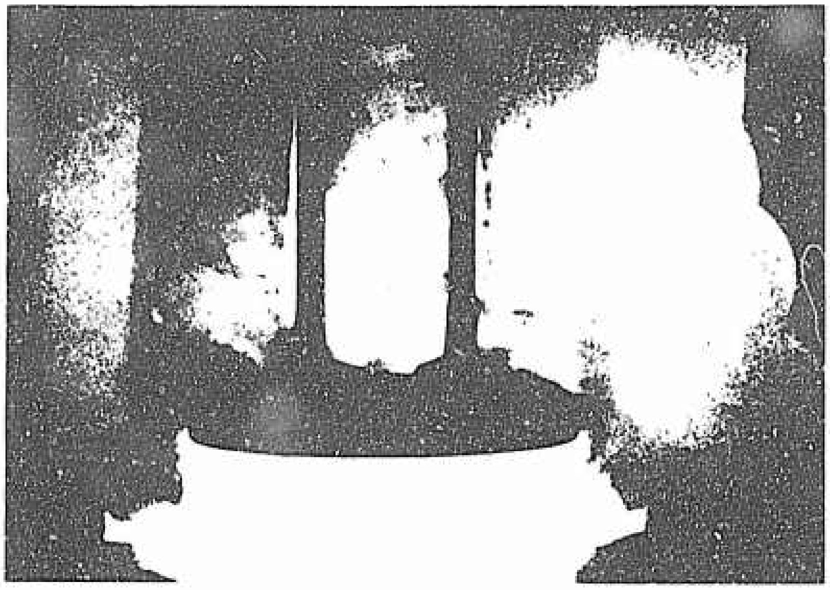


Figure 6. Plate anchor excavated after load test in snow showing the backfill and in-situ snow. (From Reference 10.)

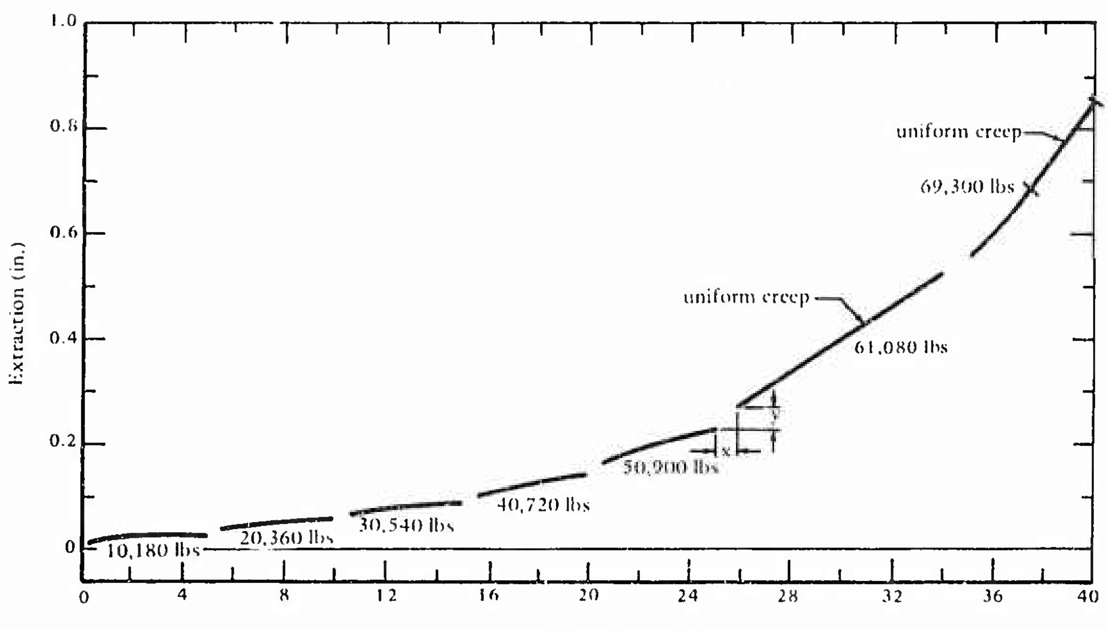


Figure 7. Extraction versus time for a 12-inch-diameter, 1-inch-thick plate anchor embedded 10 feet in snow. (From Reference 10.)

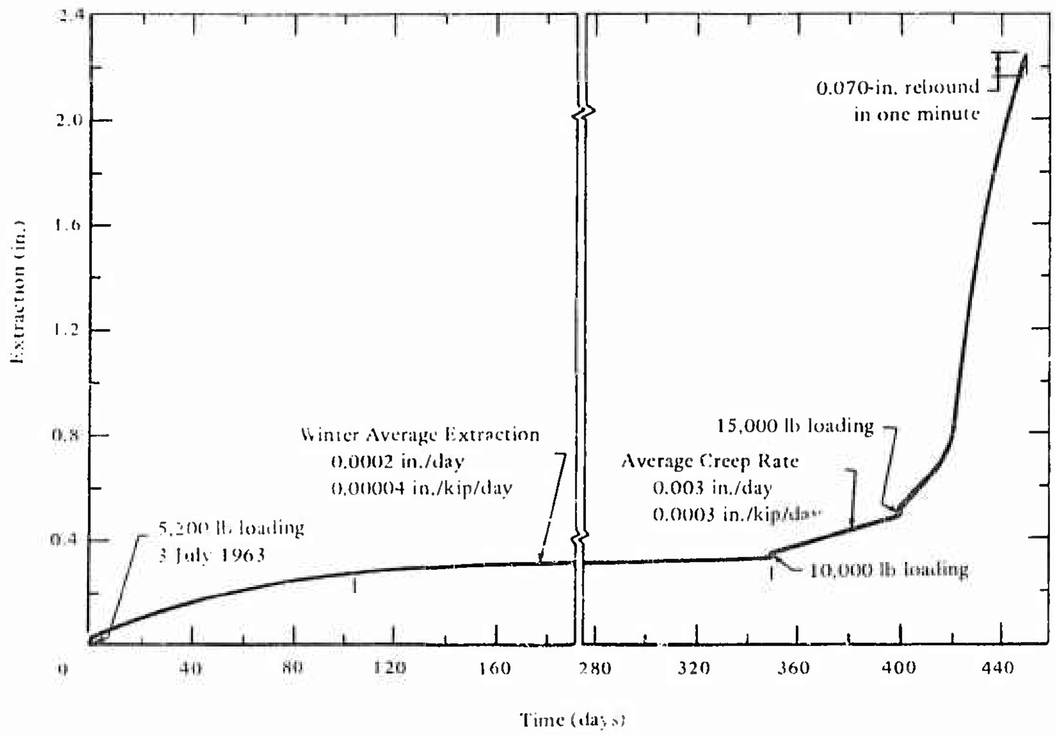


Figure 8. Extraction versus time for sustained loads on a plate anchor 12 inches in diameter and 1 inch thick embedded 8 feet in snow. (From Reference 10.)

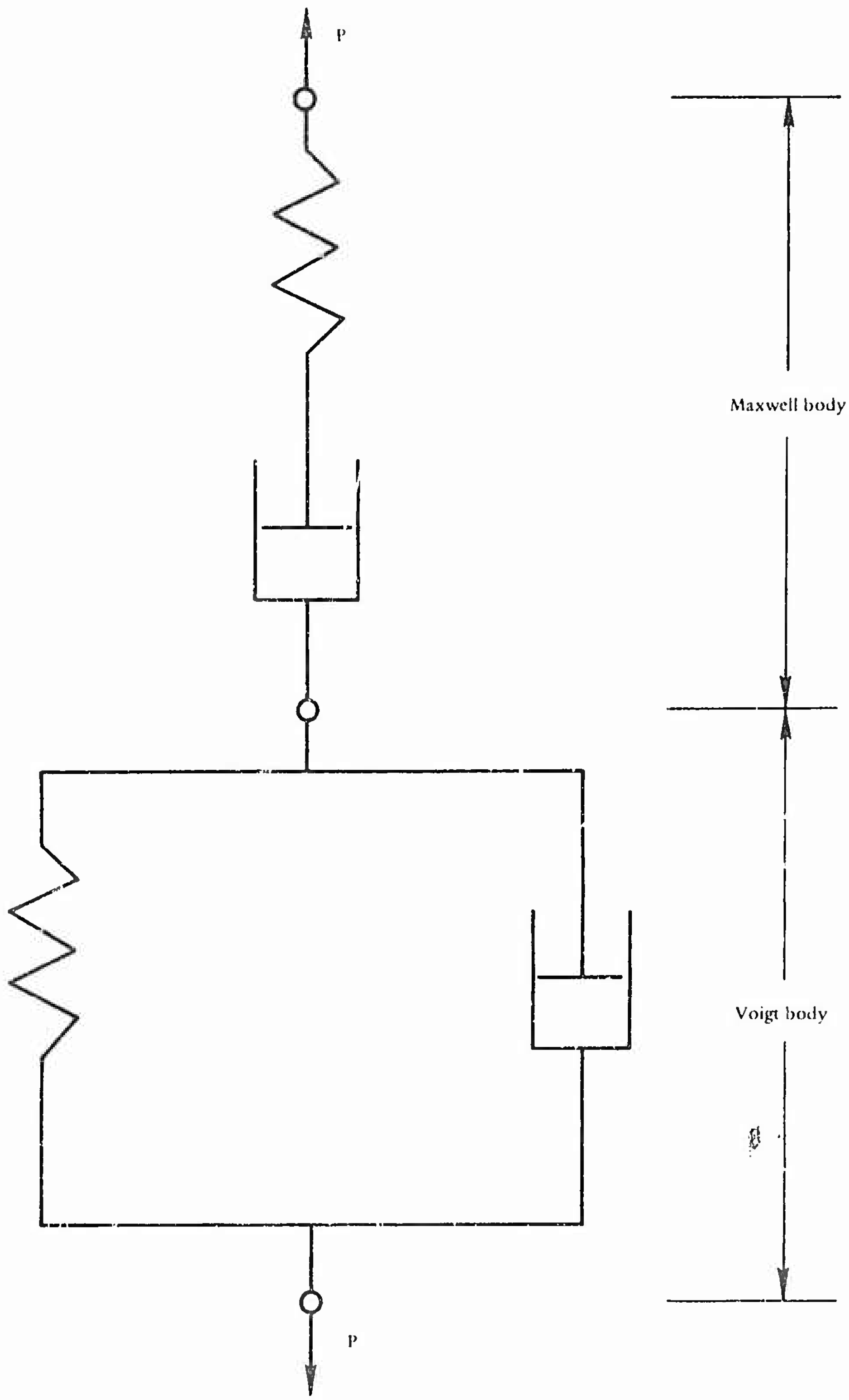
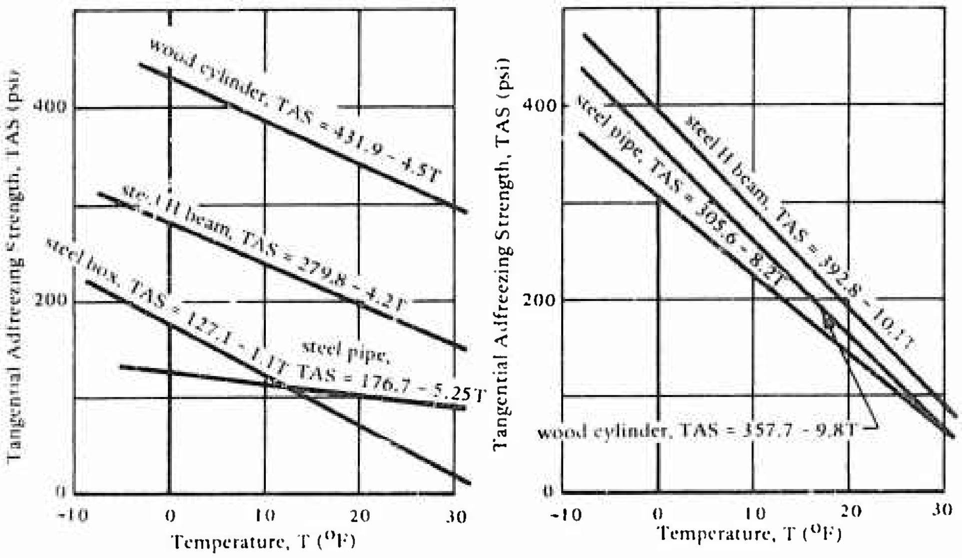


Figure 9. Rheological model of the behavior of an anchor in snow. (After Reference 10.)



(a) Freshwater backfill. (b) Slurry backfill.

Figure 10. Tangential adfreezing strength of 3-inch piles embedded in ice at various temperatures. (From Reference 11.)

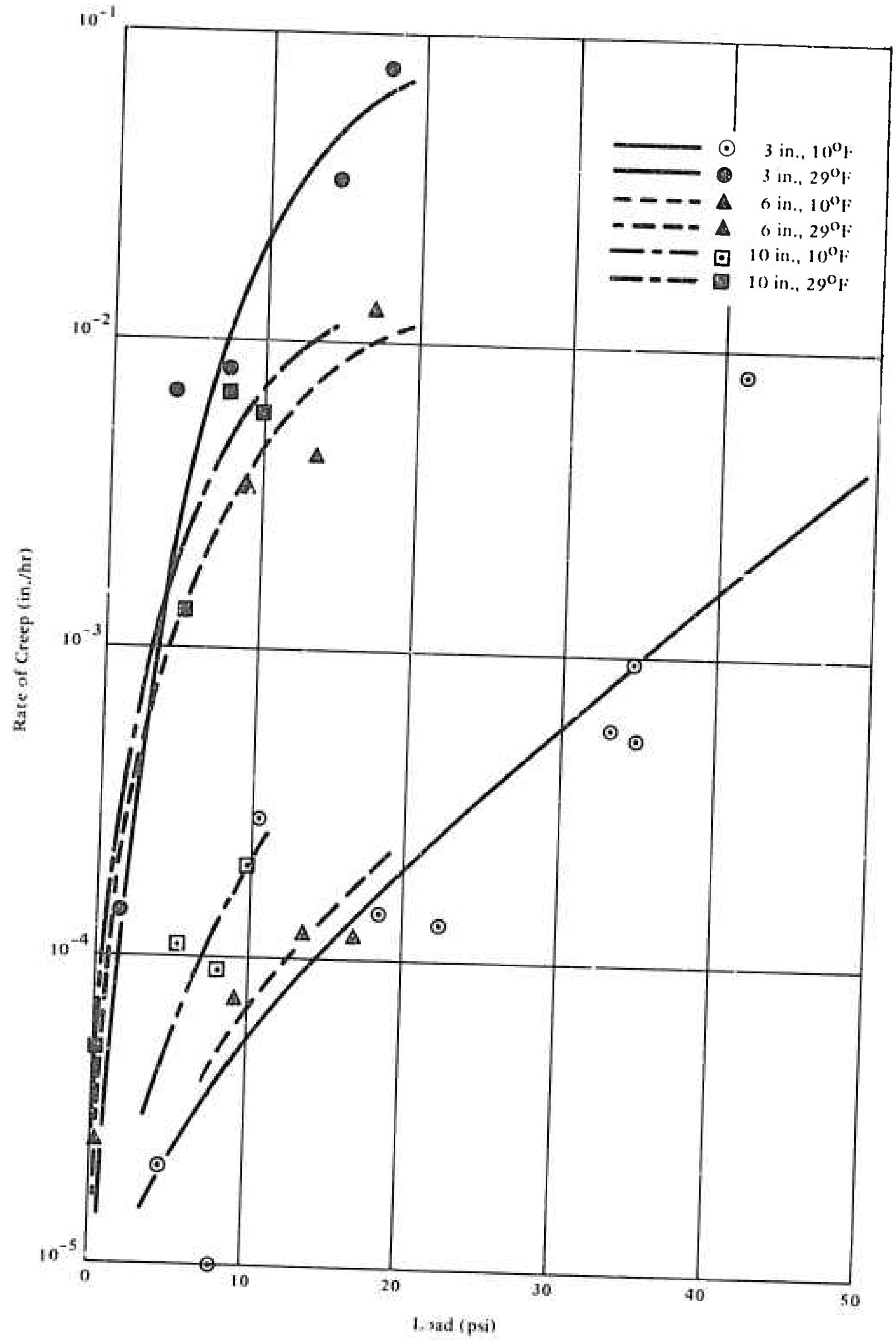


Figure 11. Rates of creep of long-term WF steel H-beam piles embedded in ice. (From Reference 11.)

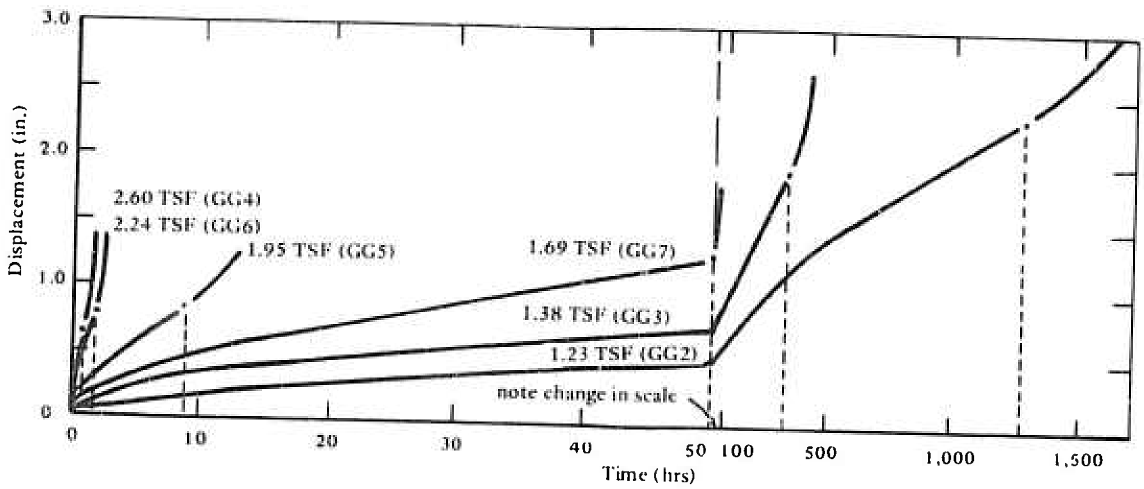


Figure 12. Results for sustained-load pull-out tests on nominally 6-inch-diameter grouted rod anchors in permafrost. (From Reference 13 for tests at Gillam site.)

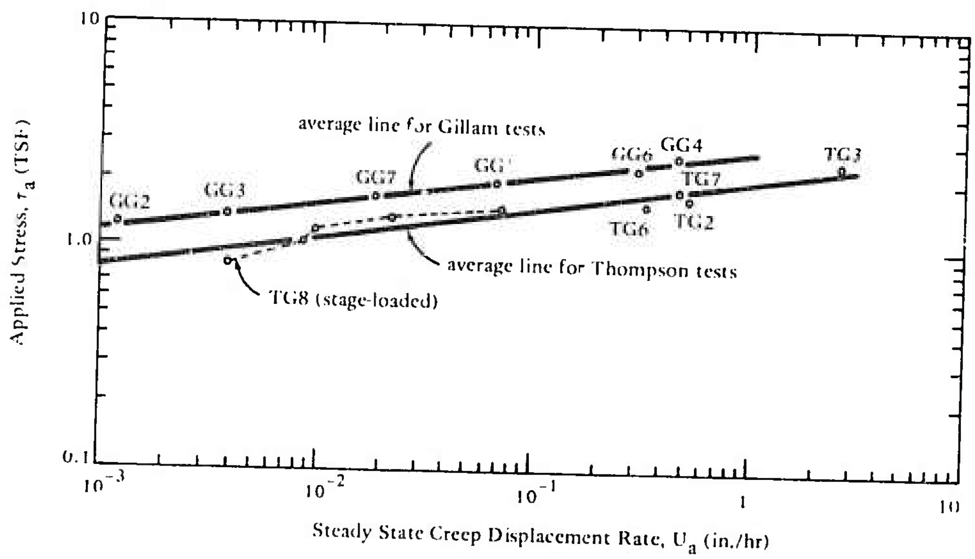


Figure 13. Steady state creep rate versus applied stress for nominally 6-inch-diameter grouted rod anchors in permafrost at Gillam and Thompson test sites in Manitoba. (From Reference 13.)

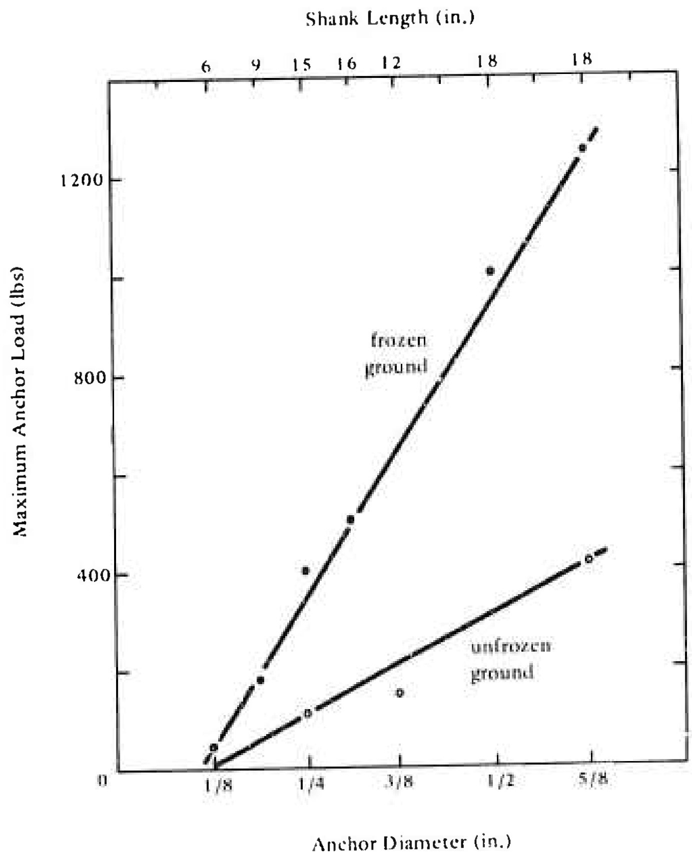


Figure 14. Results of tests on hook anchors of various shank length and diameters in frozen and unfrozen silt. (From Reference 14.)

Table 1. Basic Anchor Configurations (After Reference 8)

Designation	Description	Installation Method	Retractability	Limitations
Stakes and Multi-Stakes Combinations	These are small anchors of lengths ranging to about 16 inches and weights ranging up to the order of 1 pound and are fabricated of such materials as wood, steel, aluminum, and polypropylene.	Driven manually with a hammer or similar implement.	Retractable but difficult in frozen soil	Those stakes that lack structural integrity cannot be driven into frozen soil.
Coil Spring Anchor	This anchor is fabricated from a rod such that a corkscrew is formed on the lower end, a loop formed at the upper end with a straight portion in between.	Manually with a leverage tool through the loop.	Retractable	Limited to soft soils.
"Sea-Plane" Auger	This anchor is composed of a straight shaft with a tapered auger on the bottom end and an eye on the upper end.	Manually installed with leverage tools.	Retractable	Installation difficulties may be encountered in gravels, rocky soils, and frozen soil.
Screw Anchor with extruding prongs	This anchor has the appearance of a framing nail as used by carpenters. The lower end has screw threads and the upper end has a hole perpendicular to the long axis of the anchor. Internally it has mechanisms such that by tightening a bolt, arms are forced laterally out into the soil.	Screwed in manually with leverage tools or by power tools. When the anchor is in place, an internal bolt is tightened to force the arms laterally into the soil.	Retractable	Test results verifying the operation and effectiveness of this anchor are not available.
Helical Blade Anchor	The anchor consists of a helical blade to which tie cables are connected.	Screwed into the soil manually or by power assistance. During installation the tie cables are shielded within the center of the placement tool shaft to avoid fouling. The placement shaft is removed when the anchor is in place.	Not practicable	Rocky or large grained, frozen or unfrozen soil are difficult to penetrate with this anchor.
Elongated Screw Anchor	This anchor has screw blades along the entire length of a central shaft. The screw blade diameter tapers from both top and bottom with the largest diameter at mid height.	Screwed into the soil manually or with power assistance with a detachable rod.	Retractable	Limited by the ability to manually install the anchor or by the available power.

continued

Table 1. Continued

Designation	Description	Installation Method	Retractability	Limitations
Helical Anchor	This anchor consists of a straight rod with one turn of a helical blade at the bottom end and an eye at the top end.	Screwed into the soil by manual or power assistance.	Retractable	Rocky or large grained frozen soil may be impenetrable or may cause the anchor tie rod to shear.
Chance Eight-Way Expanding Anchor	This anchor has three basic pieces: a circular base, a rod which is attached to the center of the circular piece, and a square piece of metal of dimensions larger than the circular base with a hole in the center to fit over the rod and is cut such that eight leaves are formed and which can be retracted during placement of the anchor.	A hole is augered to the desired depth with a diameter slightly greater than the closed radius of the anchor. When the anchor is in place, the tie rod is turned causing the bottom base plate to move upward thereby causing the leaves to open.	Not retractable	Ability to auger the hole and to soils in which the anchor can open.
Three-Way Ever-Stick Expanding Anchor	This anchor is composed of three plates connected to a central rod in a manner such that an overall circular base is formed in the closed position. Articulated arms connect the plate to a centerpiece which slides up and down the rod. When the centerpiece slides down this forces the plates to move laterally into the soil.	A hole is augered to the desired depth with a diameter slightly greater than the closed diameter of the anchor. The anchor is positioned in the hole and the tie rod is turned to force the base plate laterally outward into the soil. The hole is then backfilled and tamped in layers.	Not retractable	Limited to the ability to auger the hole and ability to force the plates laterally outward into the soil.
Spaded Expandable Land Anchor	This anchor consists of a center rod, two flukes hinged to the bottom of the rod in a manner such that in a closed position the flukes are positioned vertically upward and at the top of the rod is an eye.	A power auger is used to excavate a hole of diameter slightly greater than that of the closed anchor. The anchor is then positioned in the hole and the hole is backfilled and tamped. The anchor is preloaded to open the flukes and to seat the anchor.	Not retractable	Limited to ability to auger the anchor hole.
Quadru-Expandable Land Anchor	This anchor is composed of a square central rod, four flukes that are connected by braces to a centerpiece which slides up and down the rod and an eye at the top of the square rod.	A hole is excavated manually or with power assistance to a diameter slightly larger than the anchor in the closed position. The anchor is then placed in the hole and the hole backfilled. A load is then applied to open the flukes and seat the anchor.	Not retractable	Limited by the ability to excavate the hole.

continued

Table 1. Continued

Designation	Description	Installation Method	Retractability	Limitations
Tubular Driving Stake with extruding prongs	This anchor has the appearance of an arrow. Internally it has prongs which extrude out when the cable which runs inside the shaft of the anchor is pulled.	Driven into the ground manually with a sledge or with a power hammer. When in position, the cable is loaded causing the arms to be forced outward.	Not retractable	Limited by the ability to drive the anchor into the ground.
Chance Never-Creep Anchor	This anchor is composed of two basic pieces. The first piece has the shape of half a cylinder and the second piece is a rod which connects about mid length to the outside of the cylinder half.	A hole is dug to accommodate the half cylinder in a manner such that the longitudinal axis of the cylinder is parallel with the axis of the hole. The anchor tie rod is then driven into the soil to intersect with the above hole. The half cylinder is then lowered into the hole and latched to the tie rod with the aid of a hook rod. The hole is then backfilled and tamped.	Not retractable	Limited to the ability to dig the anchor hole and to drive the tie rod.
Chance Cone Anchor	This anchor is composed of a rod, a cone with its apex connected to the bottom of the rod, and an eye at the top of the rod.	A hole with a diameter slightly larger than the base of the cone is augered to the desired depth. The anchor is then positioned in the hole and the hole backfilled and tamped.	Anchor plate is not retractable but the tie rod can be retracted by unscrewing	Limited to the ability to auger the hole.
Universal Ground Anchor (Arrowhead Anchors)	This anchor has the appearance of an arrowhead with a cable attached on its side.	The anchor is driven into the ground by a sledge hammer or other driving means with the use of a retrievable driving rod. Post tensioning is performed to set the anchor.	Not practical	Limited to areas where it can be driven into the soil.
Steel Grillage Anchor	This anchor is composed of a steel plate on top of which steel grillage is fabricated to form the anchor.	A pit is first excavated. A base assembly is then positioned on the bottom of the pit and the truss work added. The pit is then backfilled with soil and rock.	Not retractable	Limited to soils in which the pit can be dug. Relative to other anchors, this anchor required many man-hours to install.
Concrete Bell Type Anchor	This anchor has the appearance of a structural column with a footing.	A hole equal in diameter to the shaft is augered to the desired depth of the anchor. The bottom of the hole is then reamed out to form the enlarged bell	Not retractable	Limited by soil characteristics.

continued

Table 1. Continued

Designation	Description	Installation Method	Retractability	Limitations
Concrete Bell (continued)		cavity. Reinforcing rods are then placed and the concrete poured into the hole filling it to the ground level.		
Piles applied as anchors	As used in the construction industry.	Driven by means of a pile driver.	Not retractable	Lateral load limitations depends on pile structural properties.
Hook Anchor (small)	This anchor is simply a spring steel rod with an eye on one end and bent at mid length to form a V.	Driven into the soil by a hammer or similar implement with the side of the V containing the eye approximately parallel with the ground surface.	Retractable	Limited by the strength of the soil and the ability to drive the anchor into the ground.
Large Scale Ground Hook	This anchor is also in the shape of a V with the distance at the widest portion of the V approximately 4 feet. On the side of the V that remains above the ground, a shackle is installed. On the other side of the V, two angles are installed.	A 6-inch-diameter hole is augered at an angle to the surface to approximately 6 feet by the use of power equipment. The anchor is then placed in the hole.	Retractable	Limited by the ability to auger the hole and the strength properties of the soil.
VSL and Alluvium Grouted-in-Place Ground Anchor	The anchor consists of a sheath and tendons.	A hole is augered to the desired depth and the anchor assembly inserted in the hole and pressure grouted into place. In the case of anchoring in soil, the bottom portion of the hole is belled, prior to placement of the anchor assembly and grouting.	Not retractable	Ability to auger the required hole and to form the required bell at the bottom of the hole.
Rock Bolt Anchors without grout	These are commercially available rock anchors commonly used in the construction industry.	A hole is first drilled by the use of power equipment. The anchor is then inserted in the hole and locked in place by tensioning the drawing bolt.	Possible but not a general practice	Limited by the ability to drill the required hole and the strength of the embedment media.
Rock Bolt Anchors with grout	These are common rock bolts used in the construction industry.	A hole is first drilled with power equipment. The anchor is then inserted in the hole and force grouted in place.	Not retractable	Limited by the ability to drill the required hole, to properly grout the anchor in place, and the strength of the anchor media.

continued

Table 1. Continued

Designation	Description	Installation Method	Retractability	Limitations
Explosive Expanding Rock Anchor	This device consists of a jamb cylinder assembled over a tie rod. The space between the tie rod and the jamb cylinder contains an explosive charge.	A hole is first drilled in the rock and the anchor and tie rod assembly is positioned in the hole at the desired depth. The explosive charge is then detonated to cause the jamb cylinder to expand. The anchor is then pretested.	Not retractable	Limited by the ability to drill the hole and by the jamb that is achieved by detonation in the particular rock type.
Expandable Screw Anchor	The anchor has the appearance of a motor boat propeller. The blades, however, are connected eccentrically to a center rod such that when the anchor is in place, the blades can be forced laterally into the soil.	Screwed manually with leverage tools or with powered assistance. When the desired depth is reached, counter-clockwise twisting opens the anchor.	Not retractable	Limited by extremely hard soils such as large grained frozen soil.

Table 2. Patents on Apparatus and Methods for Anchoring in Ice and Frozen Ground

Title	Patent No.	Patent Date	Anchoring Medium	Description
Ice or frozen earth anchor	3,304,671	21 Feb 1967	Ice or frozen ground	This anchor consists of a cylinder within which is contained (beginning from the upper end) a compressed spring, a coil of cables, a flat plate, and a combustible substance (such as thermite). In operation, the unit is placed in a hole and the combustible material permitted to ignite. As the combustible material is consumed, the compressed spring expands and forces the components down into the hole. The heat from the ignited material causes the ice or frozen ground surrounding the lower portion of the anchor to melt. By gravity the cables are forced into this thawed area. Upon refreezing of this thawed area containing the cables, the anchor is ready for use via an eye attached to the top of the cylinder.
Ice anchor	3,157,256	25 Aug 1961	Ice or frozen ground	This anchor consists of three basic parts. The first part is a rigid metal plate with downwardly rounded marginal portions such that it has the appearance of an inverted pan with inturned edges. The second part is a metal plate similarly formed but of a depth and radius roughly one-half of the dimensions of the first part. This second part is concentrically attached to the first part. The third part is the load attaching section consisting of an eye on a spider bracket which is rigidly attached to the above plates. The anchor is installed in the following ways: placed on a leveled surface and the inverted pans filled with water through weep holes in the plates or by submerging in a shallow pool of water.

continued

Table 2. Continued

Title	Patent No.	Patent Date	Anchoring Medium	Description
Ice anchor (continued)				In both cases when the water refreezes, a firm bond between the anchor and the supporting frozen surface is developed.
Method and apparatus for improving bearing strength of piles in permafrost	3,706,204	19 Dec 1972	Permafrost	This invention consists of a pile with cylindrical or segmented cylindrical rings which extend radially outward beyond the surface of the pile and situated on the lower portion of the pile that will be embedded in permafrost below the seasonal thaw zone. The remainder of the pile above the portion embedded in permafrost has a smooth outer surface. The pile is installed by placing it in a predrilled hole and backfilling the hole with material which eventually freezes and becomes an integral part of the permafrost surrounding the hole. The intention of the invention is to increase the bearing capacity of the pile, but the invention will also improve the anchoring capacity of such piles.
Heave-proof arctic piling	3,703,812	28 Nov 1972	Seasonally frozen tundra	When freezing occurs, the tundra mass expands causing a squeezing and heaving effect on a pile. This invention utilizes this squeezing effect to minimize heaving of the pile. The invention consists of a frustrum of a right cone with a minimum base diameter of at least three times the diameter of the pile, a top diameter approximately equal to the pile diameter and a directorix angle in the range of approximately 3° to 30°. The invention is installed on a pile with the base preferably at or in permafrost and the top at the ground

continued

Table 2. Continued

Title	Patent No.	Patent Date	Anchoring Medium	Description
Heave-proof (continued)				surface. This invention is also intended to improve the performance of piles in load bearing, but the invention will also have a positive effect if the piles are used as anchors.

Table 3. Analytical Methods for Determining the Holding Capacity of Ground Anchors (After Reference 9)

Analysis Method	h/d* Applicability Range	Direction of Loading Relative to Ground Surface	Applicable Anchor Medium	Remarks
Earth Cone Method	<6	Vertical	All Soils	
Earth Pressure Method	<6	Vertical	All Soils	This method is also known as the friction cylinder method, the Swiss formula, or the Frohlick Majers' procedure.
Shearing Method	<6	Vertical	All Soils	
Balla Cone Method	<6	Vertical	See Remarks	Full scale uplift test showed that excellent agreement was found using Balla's formula for the anchors embedded in sandy soils but very poor correlation was found for the same anchors embedded in clay at a comparable depth.
Matsuo and Tagawa Cone Method	$h_2/R \leq 10$ (h_2 = depth to top of anchor base; R = anchor base radius)	Vertical	See Remarks	This method may have the same limitations as the Balla method.
Marinpol'skii Cone Method	<6	Vertical	Cohesionless Soils	This method has not been validated for cohesive soils nor for anchors classified as deep anchors.

* h – anchor embedment depth, d – anchor base diameter.

continued

Table 3. Continued

Analysis Method	h/d Applicability Range	Direction of Loading Relative to Ground Surface	Applicable Anchor Medium	Remarks
Mors Variation of the Cone Method	<6	Vertical	All Soils	
Baker and Konder Round Anchor in Sand Analysis	<6 ≥ 6	Vertical	See Remarks	Two separate procedures are provided to analyze the holding capacity of anchors with h/d ratios of less than 6 and for ratios equal to or greater than 6. These techniques were developed based on tests with circular anchors in sand.
Turner Method	<1.5 ≥ 1.5	Vertical	All Soils	Comparison of this method with the Earth Cone Method and the Shearing Method shows that considerable discrepancies exist between the computed values by these methods and test results on anchors at certain particular depths of embedment.
Bearing Capacity Theory applied to Universal Ground Anchors	Depends on the embedment material	At 45 degrees	Cohesive and Noncohesive Material	Tests of universal ground anchors in frozen soil showed that holding capacities measured were larger by as much as 100 percent over results obtained in nonfrozen soil. Placement of these anchors in frozen soil, however, is very difficult.

continued

Table 3. Continued

Analysis Method	h/d Applicability Range	Direction of Loading Relative to Ground Surface	Applicable Anchor Medium	Remarks
McKenzie Analysis for Deep Anchors	See Remarks	Horizontal	Clays	This method is applicable to deep embedment anchors at h/t ratios approximately equal to 10 or higher. (Where h = depth to the bottom of the anchor and t = the anchor base thickness.)
Rigid Ground Stakes	Not Applicable	See Remarks	Any Soil	Two methods of analysis for a rigid stake or pile are presented. The first method is for the loading parallel to the longitudinal axis of the pile or stake. The second method is with the loading perpendicular to the longitudinal axis. These methods have been used for piles in frozen soil and for 9-inch aluminum pins in frozen muskeg.
Nonrigid Ground Stake and Pile Analysis	Not Applicable	Lateral to Pile or Stake Axis	Any Soil	It was stated that this method would be applicable to permafrost conditions by determining a maximum or critical soil reaction that the frozen soil should not be subjected to in order to avoid a faster than desirable creep rate. This method is primarily to determine the stresses in the pile

continued

Table 3. Continued

Analysis Method	h/d Applicability Range	Direction of Loading Relative to Ground Surface	Applicable Anchor Medium	Remarks
Nonrigid Ground (continued)				itself and the displacements to which it is subjected to rather than the pullout capacity of the pile.
Broms Pile Analysis	Not Applicable	Lateral to Pile Axis	Any Soil	This method is similar to the method above. It provides the required dimensions and properties of the pile itself rather than the pullout capacity.
Jaky Method	Must be embedded greater than the height of the stressed zone above the anchor	Vertical	Any Soil	This method is applicable to a bell anchor similar in shape to an end bearing pile wherein a stress zone can be formed above the bell and skin frictio can be developed around the pile above this stress zone to the ground surface.
Biarez and Barrand Method	Depends on the soil type and anchor configuration	Vertical	All Soils	Several different techniques are presented to determine the uplift capacity for various anchor geometries, depth of embedment, and soil properties. Tests on cast-in-place concrete bell anchors with shaft diameters of 18-24 inches and bell diameters of 36-48 inches

continued

Table 3. Continued

Analysis Method	h/d Applicability Range	Direction of Loading Relative to Ground Surface	Applicable Anchor Medium	Remarks
Biarez and Barrand (continued)				and straight shaft piles of 18 inches diameter and 12 feet long were conducted to evaluate the validity of the Jaky Analysis and the Biarez and Barrand Analysis Methods in predicting the uplift capacity of these anchors. It was found that the calculated values by these methods were in good agreement with the test results.
Grouted Anchors	Not Applicable	Various	All Soils and Rock	The analysis technique for anchors in clays is not as good as for anchors in sand, gravel, or rock. For grouted anchors in freezing conditions the bond strength between the anchor rod and the grout may govern the capacity of the anchor. Freezing of the grout must be avoided because the bond strength between the anchor rod and the grout is reduced and, in the case of grouted anchors in rock, the bond strength between the grout and the rock is also reduced.

continued

Table 3. Continued

Analysis Method	h/d Applicability Range	Direction of Loading Relative to Ground Surface	Applicable Anchor Medium	Remarks
Tsytovich Analysis of Forces due to Adfreezing	Not Applicable	Vertical	Frozen Soil	For anchors placed in permafrost regions adfreezing forces both assist and depreciate anchor capacity. In the permafrost layer itself adfreezing forces assist in increasing the capacity of the anchor. On the other hand, in the active zone the adfreezing forces result in providing a heaving effect on the anchor, thereby reducing the capacity of the anchor.
Porkhaev ''Foundation Anchoring in Thawed Ground''	Not Applicable	Vertical	Frozen Soil	This method is based on the weight of the soil directly over the anchor but it does not consider the effect of heaving forces which occur in the active zone.

Table 4. Frozen Ground Anchors

Designation	Description	Reference Source
Dead Man Anchor	Consist of a concrete clump.	12
Pile Anchor	Pipe piles as used in the construction industry.	12
Grouted Rod Anchor	Consists of a steel reinforcing bar grouted in a drilled hole.	13
Hook Anchor	Consists of a bar bent into a ''V'' with an eye on one end.	14
The Long Thermopile	Consists of pipe columns with end closures in a manner such that pressurized propane within the columns self-refrigerate the pile by vaporization and condensation of the propane.	15
Arrowhead Universal Ground Anchors	These anchors are one-piece malleable iron castings shaped in the form of an arrowhead. It has a short shank to receive a hollow ended driving rod and two cables, one attached at the center of gravity and one eccentrically positioned. Anchors are manufactured in sizes ranging from 2-17 inches.	16
Arctic Adapter, Drive Pickets	The anchor consists of a metal baseplate nailed to the ground with steel pins or spikes. Such anchors were effective in supporting high wire entanglement fences and camouflage nets in winds to approximately 65 mph.	17
Guy Stake, GP-112/G	This anchor consists of a long cylindrical shaft sharpened on one end and equipped with a shackle on the other.	18

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